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HEAVY-SECTION FRACTURE TOUGHNESS
SCREENING SPECIMEN

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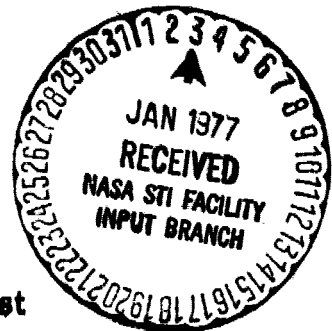
HEAVY-SECTION FRACTURE TOUGHNESS SCREENING SPECIMEN

John L. Shannon, Jr.[1], J. Keith Donald[2], and William F. Brown, Jr.[3]

ABSTRACT: Size requirements for a pin-loaded double-edge notch + crack tension specimen proposed for fracture toughness screening heavy section alloys were studied. Ranking of eight selected alloys based on the specimen's net strength was compared with that based on the valid plane strain fracture toughness separately determined. Performance of the specimen was judged on the basis of that comparison.

The specimen's net strength was influenced by three critical specimen dimensions: distance between the crack plane and the loading hole, specimen width, and specimen thickness. Interaction between the stress fields of the crack and the loading holes reduced the net strength, but this effect disappeared as the separation reached a dimension equal to the specimen width. The effects of specimen width and thickness are interrelated and affect the net strength through their influence on the development of the crack tip plastic zone. Correlation between the net strength of the screening specimen and the plane strain fracture toughness was enchanced by increasing thickness and decreasing width of the screening specimen.

The work described is intended to form the technical base for the development of a standard fracture toughness screening test method for heavy sections to supplement ASTM E-338 Standard Method of Sharp Notch Tension Testing of High-Strength Sheet Materials. Development of the test method is the responsibility of the ASTM E24.01.02 Task Group on Revision of E-338.

KEY WORDS: notch testing, fracture toughness, toughness screening test, fracture properties

Nomenclature

σ_{tu} ultimate tensile strength (ksi)

σ_{ty} 0.2% offset tensile yield strength (ksi)

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σ_c net fracture strength (crack strength) of DENC specimen (ksi)

K_{Ic} valid (according to ASTM E-399-74) plane strain fracture toughness (ksi $\sqrt{in.}$)

K_Q conditional value of plane strain fracture toughness (ksi $\sqrt{in.}$), (reference ASTM E-399-74)

INTRODUCTION

The plane strain fracture toughness K_{Ic} as defined by ASTM Method of Test E-399 [1][4] has become widely accepted as a useful measure of a material's load carrying capability in the presence of a sharp crack under conditions of high transverse constraint and small scale yielding. Minimum K_{Ic} requirements appear regularly in military and commercial specifications and form the basis of fracture control programs. However, E-399 specifies a rather complex measurement which is not generally suited to screening materials on a routine basis. Additionally, the specimen size requirements specified by E-399 frequently exceed the application section size. Neglecting one or more features specified in E-399 may result in misleading indications of crack toughness. Reference [2] demonstrates the possibility of erroneous toughness indications when Method E-399 is applied to subsized specimens. What is needed is a simpler screening test, the results of which can be correlated with valid K_{Ic} values for given material conditions and which can also be used to obtain qualitative indications of crack toughness under mixed mode conditions.

One such test is provided by ASTM Method E-338 [3] for "Sharp-Notch Tension Testing of High-Strength Sheet Materials." This method specifies a simple measurement of notch strength based on the maximum load in a

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[4]Numbers in brackets refer to the list of references appended to this paper.

tension test. It is, however, limited to thicknesses of 1/4-inch or less and employs a specimen 3-inches wide × 12-inches long. It has been suggested [4] that E-338 be supplemented with another (new) method of test which would have essentially the same screening purposes of E-338 but broader applicability in terms of increased specimen thickness and reduced planar dimensions. For this purpose a double edge notch specimen with one of the notches tipped with a fatigue crack is proposed here. This specimen will be referred to as a DENC (double edge notch+crack) specimen.

The present study is aimed at fixing the proportions and limits of application of the proposed DENC specimen. The influence of specimen width and thickness on the crack strength (net fracture strength) and apparent plane strain fracture toughness of the specimen has been determined for eight alloys covering a broad range of types, strengths and toughnesses. For each specimen width-thickness combination, alloy ranking on the basis of crack strength is compared with that based on K_{Ic}'s determined according to ASTM E-399-74 using three-point bend specimens. The results support a recommendation to the ASTM Committee E-24 on Fracture Testing of Metals for the adoption of the DENC specimen for screening heavy section materials with reference to their fracture toughness. A discussion is presented on the effects of specimen size on the apparent plane strain fracture toughness evident from the results.

DENC SPECIMEN

The proposed double edge notch + crack (DENC) specimen, Fig. 1, contains two symmetrically opposed notches, one of which is fatigue cracked and the other provided with an easily machined, relatively blunt tip. The blunt notch has the same maximum length as the opposing notch plus fatigue crack and its purpose is to produce a near-balanced stress field. It is recognized that since the fracture will run from the fatigue crack, the "balanced"stress field will not be maintained to failure. However, the sharp double edge notch (DEN) specimen of E-338 generally exhibits this behavior and experience shows that the consequent eccentricity in loading does not impair the usefulness of that test.

The selection of a symmetrically loaded tension specimen rather than a bend specimen (or an eccentrically loaded tension specimen) is based on the large amount of experience that has been accumulated using this type of specimen in the screening of sheet alloys. It is generally recognized that the nominal net strength of such a specimen is a useful quantity in judging the relative crack toughness, providing this strength is below the conventional tensile yield strength. In contrast, there is no generally recognized way of expressing the result from a bend test or an eccentrically loaded tensile test of cracked specimens, nor of relating the result to a commonly reported material property such as the yield strength. In addition, the DENC specimen provides, in its gross strength, a lower-bound estimate of the gross strength of a (relatively large) structure containing a through-crack of the same length as the crack in the DENC specimen.

Specimen Length

The specimen has been made as short as possible consistent with avoiding excessive interaction between the stress fields of the loading holes and the edge notches. The lower limit on length was established by the results[5] shown in Fig. 2 for tests on 18Ni (300) maraging steel sheet specimens heat treated to three different strength (toughness) levels. These results show the crack strength-to-yield strength ratio to be nearly independent of the distance between the notch plane and the loading hole centers if that distance is greater than about 1W. Notice that for a distance of 0.75W the strength ratio is considerably depressed for the two tougher metal conditions. It seems possible that this effect could suppress or even reverse differences in apparent toughness between two material conditions where those differences were established by tests on specimens with d > 1. Based on these results the specimen total length has been set at 3.3W.

[5]These results were obtained by R. T. Bubsey of NASA-Lewis Research Center, Cleveland, Ohio, in an earlier, unpublished study. The 18Ni (300) maraging steel sheet specimen material is not included in the list of investigated alloys in Table I.

Notch Length

The total notch length (depth) selected is 0.5W rather than 0.3W as specified for sheet in E-338. This permits the use of a larger loading pin without increasing the possibility of specimen head failure, and extends the thickness range that can be tested using a given width specimen. The pin diameter is taken equal to the net section width (0.5W) and with these proportions fracture will always occur at the notched section provided the crack strength is less than the tensile strength.

Specimen Width and Thickness

Little is known about the effects on crack strength of varying the ratio of width to thickness of crack toughness specimens. There is a complex interaction between the effects of width and thickness on the crack strength through their influence on the development of the crack tip plastic zone. The zone will decrease with increasing thickness and its opportunity for full development will be decreased by decreasing width. There is no way to eliminate this interaction except by making the width so large at a given thickness that further increases will have no effect. The lower limit of W/B > 12 prescribed in E-338 is supposed to approximate this condition. However, that value was selected on the basis of formal calculations which are no longer acceptable and it is quite likely that the limiting value of W/B, if one exists, depends on the material. In any event, this effect in a practical screening test will have to be tolerated because even if a lower limit of W/B could be determined, and it did not vary with material, it would doubtless require unacceptably large specimens for testing thick materials. In practice, the limiting W/B ratio might well be determined by the difficulty in producing a uniform and controlled amount of fatigue crack extension.

The present program was designed to explore the complex influence of specimen width and thickness on the fracture strength of the proposed DENC screening specimen. The approach was to vary thickness for several specimen widths and observe the variability of ranking, on a toughness basis, for a wide variety of alloys. The thickest gage was sufficient to provide valid plane strain fracture toughness values using standard E-399

bend specimens, and those were used as reference for the ranking established on the basis of the crack strength-to-yield strength ratios for the various specimen sizes investigated. The specimen widths, thicknesses and width-to-thickness ratios studied are presented in Fig. 3. The largest W/B value was based on specimen size economy; the smallest on a consideration of loading pin strength (discussed below). Because of a shortage in available test material, only one W/B ratio was studied for 6061 alloy. The series of tests for Ti-8Mo-8V-2Fe-3Al alloy is incomplete due to the loss of some specimens in heat treatment.

Loading Pins

The maximum thickness that can be tested using a particular width is determined in part by the requirement that specimen failure occur before pin failure. In this regard, the lowest W/B ratio studied (W/B = 2) was limiting and required that the loading pin material have a tensile yield strength about 50 percent higher than that of the specimen. Pins were made of fully aged 18Ni (300) maraging steel, ensuring failure in the test section for specimen yield strengths up to 200 ksi. Stronger materials were tested but were sufficiently brittle that failure occurred in the cracked section well before the yield strength of the pin was reached.

MATERIALS AND PROCEDURE

The alloys used in this study are listed with their heat treatments and conventional tensile properties in Table I. All were obtained as one-inch thick plate with the exception of 6061 alloy, which was two inches thick. In every case, test specimens were extracted symmetrically with respect to the midplane of the plate stock. Test direction for all alloys except 6061 and 2419 was longitudinal (L-T crack plane orientation); for 6061 and 2419 it was transverse (T-L crack plane orientation).

Conventional tensile properties were determined in accordance with ASTM Standard Method E-8-69 using 0.5-inch diameter specimens. Plane strain fracture toughness determinations were made in full compliance with ASTM Standard Method E-399-74 using 1-inch thick three-point bend

specimens. These tests were all performed at the NASA-Lewis Research Center.[6]

Preparation and testing of the DENC specimens were done at Ocean City Research Corporation.[7] Crack starters were fatigue cracked before the balancing notches were machined. Fatiguing was done in three-point bending following complete heat treatment, and conformed to the practice stipulated for fracture toughness specimens in E-399-74. Shimming techniques described in reference [5] were used to balance the crack length indicated on each surface. The surface lengths usually differed by less than 0.010 inch, and greater differences had no sensible effect on specimen strength. Crack shapes (straightness) rarely differed from that required by E-399-74, and then only slightly and with no apparent influence on specimen performance. Balance notches were machined after precracking and to a depth equal to the total length of starter plus fatigue crack, using the surface crack length as an indicator (adjusted for anticipated crack front curvature[8]). In most cases this resulted in crack and balance notch lengths that differed from their average by no more than 5 percent. In cases of mismatch, the crack was usually longer than the balance notch. In all but four instances, the sum of the crack plus balance notch lengths was between 0.50W and 0.55W and the exceptional cases were not far out of this range. Crack strengths were calculated by dividing the maximum test load by the specimen's original uncracked area. Initial crack lengths were determined after failure using the procedures given for K_{Ic} tests in E-399-74.

The need for low eccentricity of loading in fracture testing brittle materials is widely recognized. Bending moments in the plane of the DENC specimen were minimized by (1) matching the lengths of the crack and the balance notch (to the extent described above) and carefully locating these

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[7]Ocean City Research Corporation, Del Research Division, 427 Main Street, Hellertown, Pennsylvania, 18055.

[8]Preliminary specimens of each alloy were fatigue cracked, notched and tested to determine the amount of crack front curvature to be accounted for in establishing the balance notch lengths of all subsequent specimens.

and the loading pin holes with respect to the load axis and, (2) rotation of the specimen about the loading pins, which could take place at low loads because of low friction between the pins and the smooth surfaces of the specimen pin holes. Bending moments in the plane perpendicular to the specimen were minimized by the use of carefully machined, rigid load clevises and fixturing, and best-effort positioning of the specimen within the clevises using visual sighting as reference.

The effectiveness of the above procedure in reducing load eccentricity, and the success with which the crack and balance notch lengths were matched and the crack shapes were controlled, is indicated by the good agreement between replicate tests. Scatter was significant only for certain of the D6aC and 18Ni (250) maraging steel tests, and probably due to metallurgical variations rather than variations in specimen preparation and test procedure.

This program offered a unique opportunity to measure the separate influences of specimen width and thickness on the plane strain fracture toughness. For this, knife edges of the type specified for K_{Ic} specimens in E-399-74 were machined into the crack mouths and fitted with a standard clip-in displacement gage in order to obtain load vs displacement records analyzable for K_Q. Those results are discussed separately in the Appendix.

RESULTS

The effect of thickness on the crack strength-to-yield strength ratio is presented in Figs. 4 thru 10 for all but 6061 alloy, which was tested in only one gage. As expected, increasing thickness continually lowers the ratio for the toughest alloys (2419, 7075 and Ti-6Al-4V) and has no influence on the brittlest (Ti-8Mo-8V-2Fe-3Al and 300M). For the alloys of intermediate toughness (D6aC and 18Ni (250) maraging steels), the ratio first drops and then becomes constant with increasing thickness. Leveling occurs at lesser thicknesses, the less the specimen width. Width and thickness therefore appear synergistic in their influence on plastic zone development at the advancing crack front: increasing thickness impedes plastic zone development more effectively when it is already frustrated by fore-shortened specimen width.

The influence of specimen width is presented for 0.50-inch thick specimens in Fig. 11. The reduction in crack strength-to-yield strength ratio with increasing width (crack length) is as expected. The curves for the more brittle alloys follow the square root relationship with crack length; those for the tougher alloys predictably do not.

The performance of the DENC specimen in ranking the eight program alloys is displayed in Table 2, which lists the alloys in descending order of plane strain fracture toughness (expressed as the crack size factor, $(K_{Ic}/\sigma_{ty})^2$), and their crack strengths and crack strength-to-yield strength ratios for all combinations of width and thickness studied. Bar graphs comparing the DENC specimen data with K_{Ic} data from standard bend specimens appear in Figs. 12 thru 15. For all width-thickness combinations, the DENC specimen had no trouble identifying the most tough and least tough metal conditions. However, its ability to discriminate amongst levels of toughness in the intermediate range varied with specimen geometry.

In order to examine the DENC specimen ranking capability at intermediate toughnesses, the ordinate scales in Figs. 12 thru 15 were made fine and were adjusted so that the σ_c/σ_{ty} bars and the $(K_{Ic}/\sigma_{ty})^2$ bars were matched in height for the most tough and the least tough alloys, accentuating the differences at intermediate toughnesses.

The results show that agreement between the DENC specimen ranking (on the basis of σ_c/σ_{ty}) and the K_{Ic} specimen ranking (on the basis of the crack size factor $(K_{Ic}/\sigma_{ty})^2$) improves as the DENC specimen thickness is increased and width decreased. The practical effect of increasing thickness and decreasing width is to inhibit plastic zone development at the crack tip and, for the DENC specimen fracture, approach conditions of plane strain and small scale yielding characteristic of the K_{Ic} test. This effect results in a flattening of the load vs crack mouth displacement trace, so that P_{max}/P_Q approaches unity.

The two width-thickness combinations producing $W/B = 8$ gave twin results, typified by those for $W = 4$ inch, $B = 1/2$ inch in Fig. 12. The performance of the DENC specimen of these proportions is wholly unsatisfactory. Where substantial changes in toughness, $(K_{Ic}/\sigma_{ty})^2$, take place, none is

indicated by the σ_c/σ_{ty} ratio (compare 2419 with 7075). Conversely, where no toughness change exists, change is indicated by the σ_c/σ_{ty} ratio (compare Ti-6Al-4V, and D6aC and 18Ni (250) maraging steels). And while the toughness of 18Ni (250) maraging steel is only slightly less than D6aC steel, the DENC result suggests the reverse is true, and substantially so!

For the 1/2 inch thickness, reducing the width to one inch (W/B = 2) beneficially interferes with plastic zone development and produces fracture approaching K_{Ic} conditions, to an extent that an excellent correlation between σ_c/σ_{ty} and $(K_{Ic}/\sigma_{ty})^2$ obtains. This is shown in Fig. 13. Where the toughness changes, these are indicated by the σ_c/σ_{ty} ratio. Where the toughness is unchanged, so is the strength ratio. And there are no juxtapositions in the rankings.

Reducing the thickness to 1/4 inch (increasing W/B to 4) disturbs the correlation in the same manner as increasing width: compare Fig. 14 for W = 1 inch, B = 1/4 inch with Fig. 12 for W = 4 inch, B = 1/2 inch. Increasing the thickness beyond 1/2 inch (while maintaining W/B = 2) offers no improvement (see Fig. 15), but a penalty in material economy.

For the 1-inch thickness, a relaxation in the width restriction can be made. Thus, W/B = 4 for B = 1 inch gives nearly the same result as W/B = 2. Smaller gages for W/B = 4 give results which are subject to the same objection as for W/B = 8.

CONCLUSION

The DENC specimen shows promise for screening alloys with reference to their plane strain fracture toughness in sections up to one inch and at net section stresses up to (and slightly exceeding) the tensile yield strength. This capability lies in the correlation of alloy ranking in terms of the specimen's crack strength-to-yield strength ratio with alloy ranking in terms of the plane strain fracture toughness determined according to ASTM E-399-74.

Correlations were obtained for specimen proportions of W/B = 2 in combinations of W = 2 inch, B = 1 inch and W = 1 inch, B = 1/2 inch, as shown in Figs. 13 and 15. Choice between the two sizes would likely be

determined by factors such as product size, application thickness, or equipment limitations. Whichever is chosen, screening should be done using specimens of a single size.

The results presented here constitute an adequate technical base for the development of a standard screening test method for heavy sections using the proposed DENC specimen. Development of a test method using this specimen has been assigned the ASTM E24.01.02 Task Group on the Revision of E-338. The extent to which the DENC specimen can be used in establishing relations between $(K_{Ic}/\sigma_{ty})^2$ and σ_c/σ_{ty} that might be employed in product quality control must await the development of sufficient additional data to permit the application of suitable statistical procedures [6].

APPENDIX:

K_{Ic} DETERMINATIONS FROM DENC SPECIMENS

Load vs displacement records were obtained from all DENC specimens and analyzed for K_Q's using the procedures of ASTM E-399-74 (appropriately interpreted for the DENC specimen). Secant slopes were determined from compliance calibrations on DENC specimens with balance notches and cracks (simulated) covering the entire range encountered in the test program. Bowie's analysis [7] for stress intensity factors was used for the K_Q calculation, and gave essentially the same result as other currently available solutions [8].

The influence of crack length and thickness on K_Q was in substantial agreement with that reported previously by Jones and Brown [2]. K_Q increased with crack length, and the magnitude f that effect depended on the shape of the load vs displacement curves as influenced by specimen thickness. The thickest specimens exhibited the flattest curves and the smallest effects of crack length. When the thickness was less than the minimum stipulated in E-399-74 for valid K_{Ic} determination, K_Q was strongly dependent on crack length: specimens with short crack lengths and insufficient thickness yielded unchanged or substantially depressed values of K_Q, those with long cracks and insufficient thickness yielded unchanged or inflated values.

The largest specimens appeared to satisfy all the various specimen size and shape requirements, and test record qualifications of E-399-74 for standard K_{Ic} tests but produced values about 10 percent below the valid K_{Ic} determined with bend specimens. This is not surprising since the DENC specimen stress field is slightly nonsymmetrical, and the stress intensity factor solution used was that for symmetrical edge cracked plate. This disparity, however, would not be expected to alter the trends observed for varying crack length and thickness.

In summary, the results are precautionary against the use of subsized specimens for K_{Ic} testing and show that conservative results are obtained from DENC specimens when the size requirements of E-399-74 are satisfied and symmetrical edge cracked plate stress intensity factor solutions are used for computation of K_Q.

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Table 1. Heat treatments and conventional tensile properties of alloys investigated.

Alloy	Heat Treatment	Conventional Tensile Properties[*]			
		σ_{tu} ksi	σ_{ty} ksi	e(2-in) percent	RA percent
6061	T651	48.6	45.0	12.0	24.0
2419	T851	67.3	52.7	12.7	22.1
7075	T7351	75.3	64.7	12.4	26.4
Ti-6Al-4V	$\alpha+\beta$ rolled + 1400°F, 1 Hr, FC	137.3	131.4	14.9	31.2
D6aC	1700°F, 1-1/2 Hrs, SQ @ 975°F, hold 2 Hrs, OQ + 1025°F, 2 Hrs, AC + 1025°F, 2 Hrs, AC	236.6	212.0	12.2	43.8
13Ni (2) Maraging	1500°F, 4 Hrs, AC + 900°F, 3 Hrs, AC	256.7	250.3	13.8	52.4
Ti-8Mo-8V-2Fe-3Al	1600°F, 1 Hr, WQ + 1000°F, 8 Hrs, AC	180.5	173.9	3.2	4.6
300M	1600°F, SQ @ 1000°F, hold 1 Hr, OQ @ 110°F, hold 1/2 Hr, AC + 575°F, 2 Hrs, AC + 575°F, 2 Hrs, AC	299.2	243.4	9.6	38.4

[*] Longitudinal direction, except transverse for 6061 and 2419 alloys.

Table 2. Effects of width and thickness on performance of DENC fracture toughness screening specimen.

ALLOY	TEST DIRECTION[1]	σ_{ty}[2] ksi	K_{Ic}[3] ksi√in.	$(K_{Ic}/\sigma_{ty})^2$ in.	W/B = 4 W = 1 in. B = 1/4 in. σ_c[4] ksi	σ_c/σ_{ty}	W/B = 2 W = 1 in. B = 1/2 in. σ_c[4] ksi	σ_c/σ_{ty}	W/B = 8 W = 2 in. B = 1/4 in. σ_c[4] ksi	σ_c/σ_{ty}	W/B = 4 W = 2 in. B = 1/2 in. σ_c[4] ksi	σ_c/σ_{ty}	W/B = 2 W = 2 in. B = 1 in. σ_c[4] ksi	σ_c/σ_{ty}	W/B = 8 W = 4 in. B = 1/2 in. σ_c[4] ksi	σ_c/σ_{ty}	W/B = 4 W = 4 in. B = 1 in. σ_c[4] ksi	σ_c/σ_{ty}
6061	T, T-L	45.0	28.0	.387	///	///	47.7	1.06	///	///	///	///	///	///	///	///	///	///
2419	T, T-L	52.7	32.2	.373	55.5	1.05	51.8	.983	53.6	1.02	45.3	.860	41.1	.780	39.0	.740	33.2	.630
7075	L, L-T	64.7	29.4	.206	56.8	.878	54.8	.847	58.2	.900	48.4	.748	36.3	.561	47.0	.726	30.1	.465
Ti-6Al-4V	L, L-T	131.4	54.1	.170	121.1	.922	105.8	.805	118.2	.900	96.4	.734	74.2	.565	88.5	.674	57.7	.439
D6aC	L, L-T	212.0	86.9	.168	162.8	.768	161.7	.763	132.5	.625	114.9	.542	118.5	.559	80.7	.381	78.4	.370
18Ni (250) Maraging	L, L-T	250.3	101.5	.164	184.5	.737	191.8	.766	171.3	.684	137.4	.549	138.7	.554	123.6	.494	95.3	.381
Ti-8Mo-8V-2Fe-3Al	L, L-T	173.9	58.2	.112	///	///	///	///	82.2 (2)	.473	79.1 (2)	.455	78.0 (2)	.448	55.2 (1)	.317	54.1 (3)	.311
300M	L, L-T	248.4	55.6	.050	109.9	.442	110.9	.446	70.9	.285	73.2	.295	76.3	.307	47.7	.192	50.1	.202

[1]First symbol σ_{ty} direction, second symbol K_{Ic} and σ_c directions. Reference ASTM E-399-74 nomenclature.
[2]Each value average two tests minimum.
[3]Each value average three tests minimum.
[4]Each value average three tests except for Ti-8Mo-8V-2Fe-3Al alloy, for which number of tests is indicated in parentheses below values.
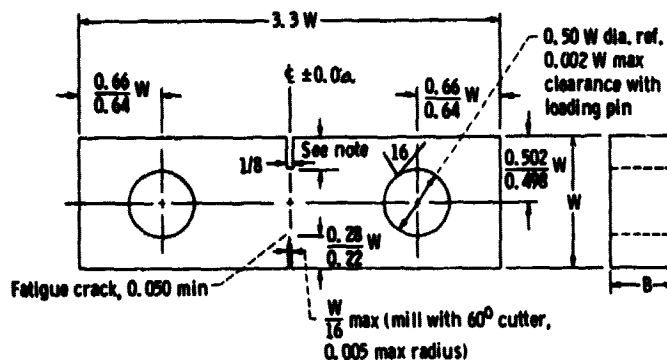
Note: Slot to be machined after opposing notch is fatigue cracked and is
to match the average total length of opposing notch plus fatigue
crack ± 0.002.

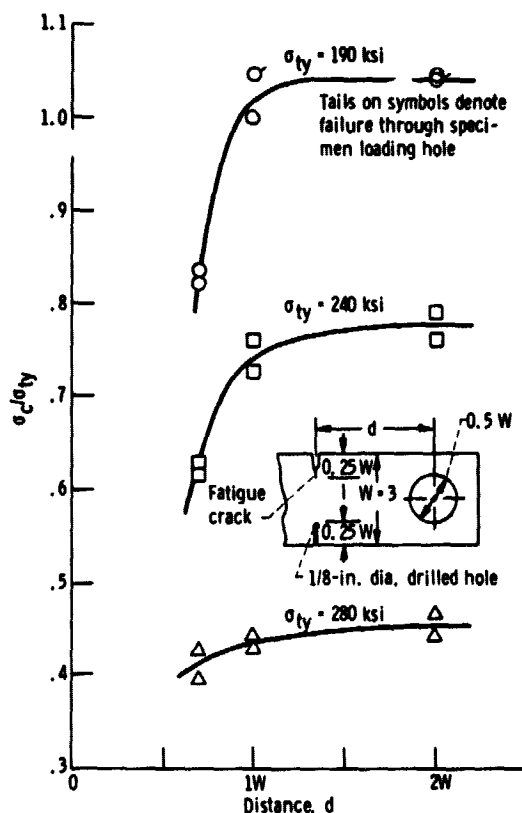Figure 1. - Double edge notch + crack (DENC) specimen. (Dimensions in inches.)

Figure 2. - Effect of distance d from loading hole center-
line to notch plane on crack strength-to-yield strength
ratio for 1/8-inch, 18 Ni (300) maraging steel sheet at
three strength (toughness) levels.

Width, W, in.

	1	2	4
	Width-to-thickness ratio, W/B		
1/4	4	8	-
1/2	2	4	8
1	-	2	4

Thickness, B, in.

Figure 3. - Specimen widths, thicknesses and width-to-thickness ratios investigated.
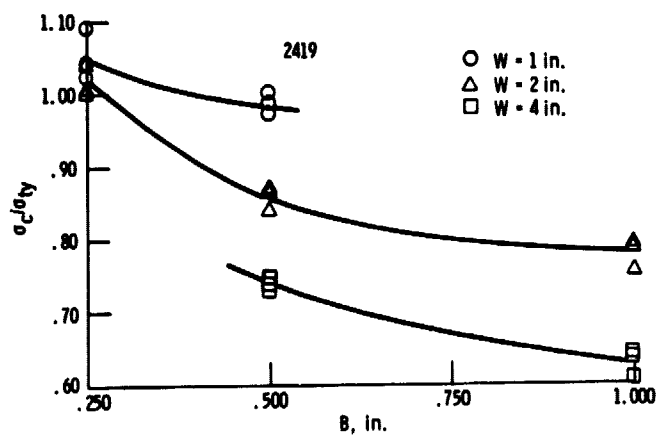
Figure 4. - Effect of thickness on the crack strength-to-yield strength ratio of the DENC specimen for 2419 alloy.
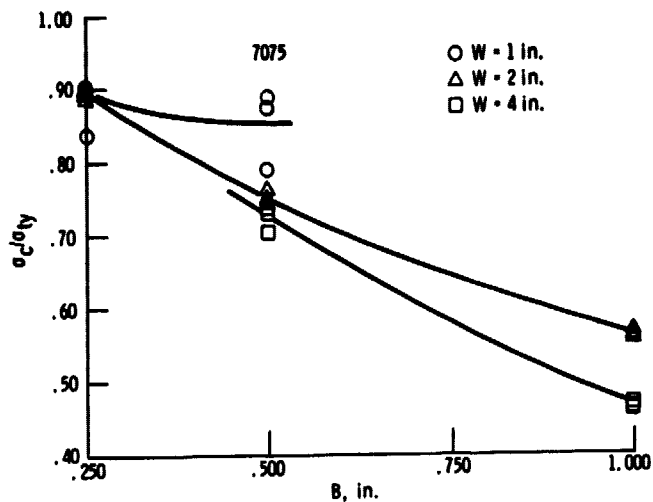
Figure 5. - Effect of thickness on the crack strength-to-yield
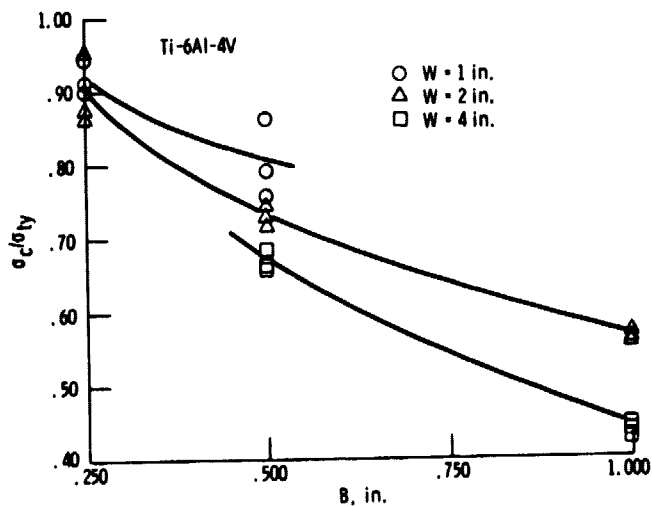strength ratio of the DENC specimen for 7075 alloy.

Figure 6. - Effect of thickness on the crack strength-to-yield
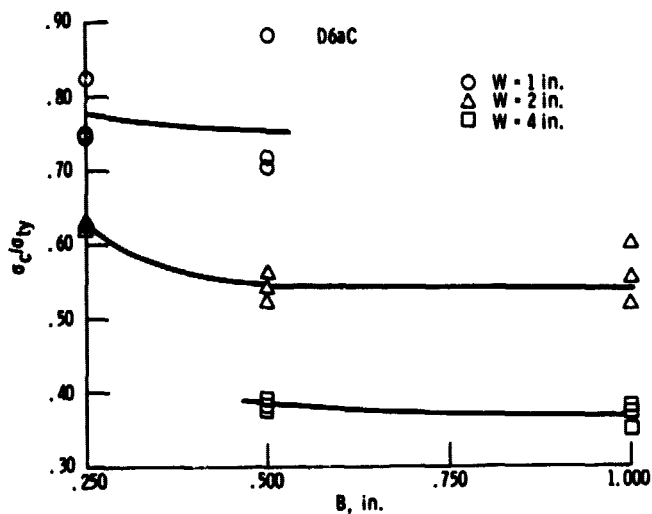strength ratio of the DENC specimen for Ti-6Al-4V alloy.

Figure 7. - Effect of thickness on the crack strength-to-yield
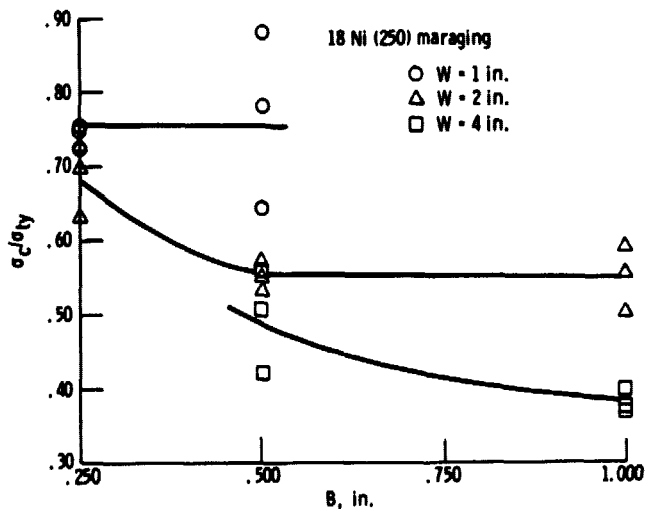strength ratio of the DENC specimen for D6aC steel.

Figure 8. - Effect of thickness on the crack strength-to-yield
strength ratio of the DENC specimen for 18 Ni (250) maraging
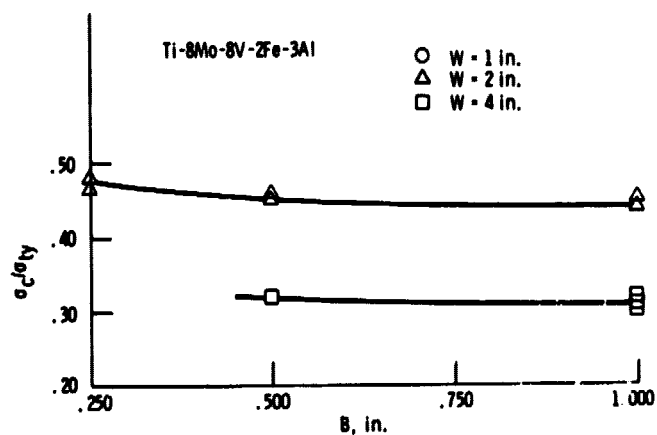steel.

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Figure 9. - Effect of thickness on the crack strength-to-yield strength ratio of the DENC specimen for Ti-8Mo-8V-2Fe-3Al alloy.
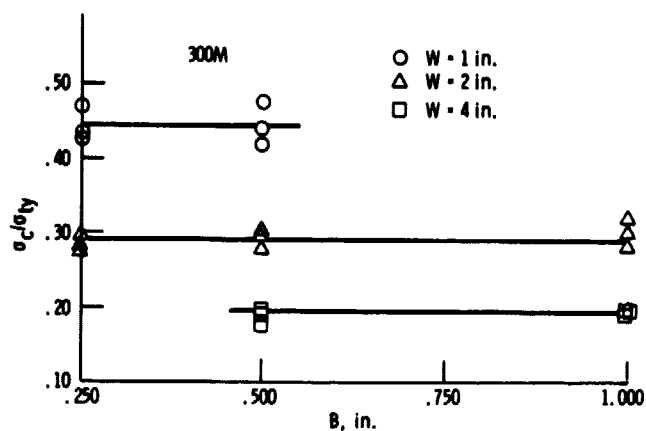

Figure 10. - Effect of thickness on the crack strength-to-yield strength ratio of the DENC specimen for 300M steel.
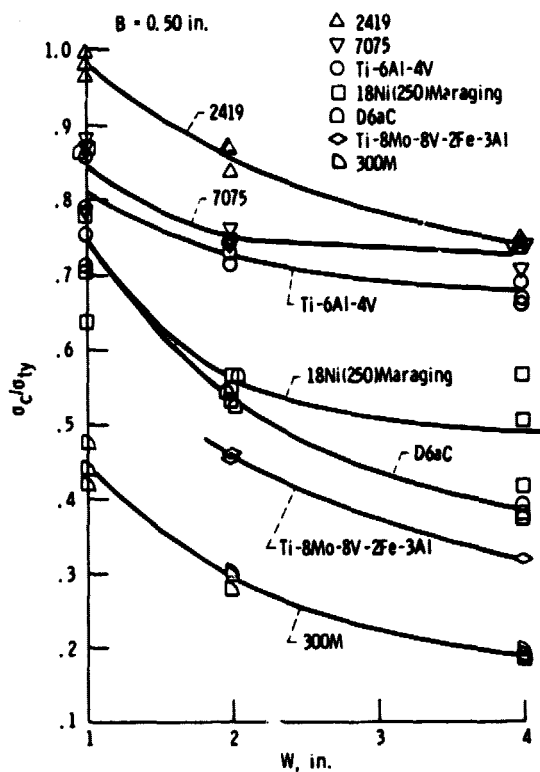
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Figure 11. - Effect of width on the crack strength-to-
yield strength ratio of the DENC specimen.

Figure 12. - Alloy ratings by DENC screening specimen and by K_{I_c} data for W/B - 8, W - 4, B - 1/2.

W/B = 2, W = 1 in., B = 1/2 in.

$\left(\dfrac{\sigma_c}{\sigma_{ty}}\right)\left(\dfrac{K_{I_c}}{\sigma_{ty}}\right)^2$

σ_c/σ_{ty}

$(K_{I_c}/\sigma_{ty})^2$

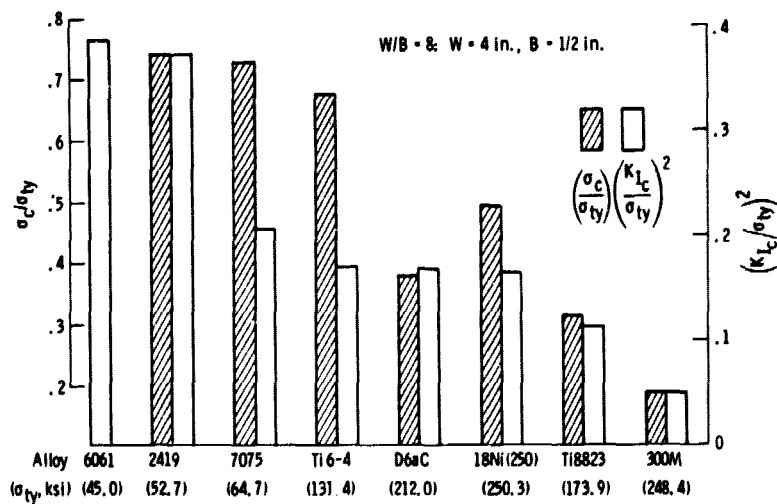| Alloy	6061	2419	7075	Ti 6-4	D6aC	18Ni(250)	Ti8823	300M
(σ_{ty}, ksi)	(45.0)	(52.7)	(64.7)	(131.4)	(212.0)	(250.3)	(173.9)	(248.4)

Figure 13. – Alloy ratings by DENC screening specimen and by K_{I_c} data for W/B = 2, W = 1, B = 1/2.

W/B = 4, W = 1 in., B = 1/4 in.

$\left(\dfrac{\sigma_c}{\sigma_{ty}}\right)\left(\dfrac{K_{I_c}}{\sigma_{ty}}\right)^2$

σ_c/σ_{ty}

$(K_{I_c}/\sigma_{ty})^2$

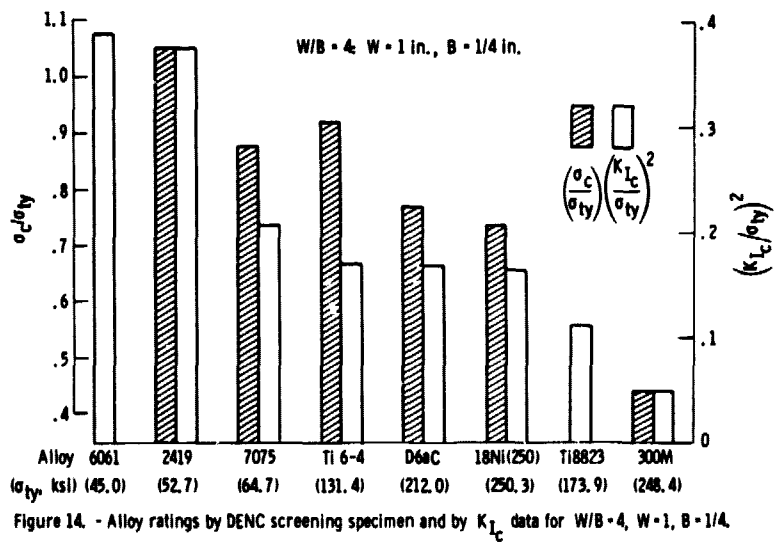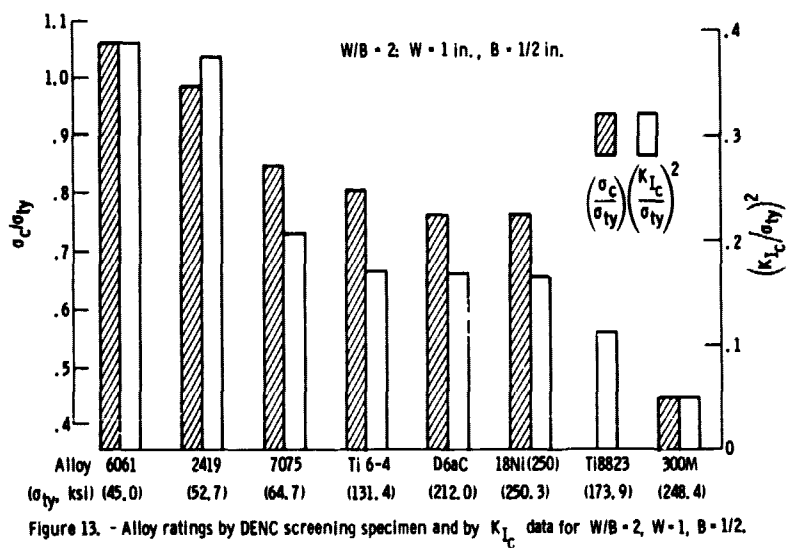| Alloy	6061	2419	7075	Ti 6-4	D6aC	18Ni(250)	Ti8823	300M
(σ_{ty}, ksi)	(45.0)	(52.7)	(64.7)	(131.4)	(212.0)	(250.3)	(173.9)	(248.4)

Figure 14. – Alloy ratings by DENC screening specimen and by K_{I_c} data for W/B = 4, W = 1, B = 1/4.
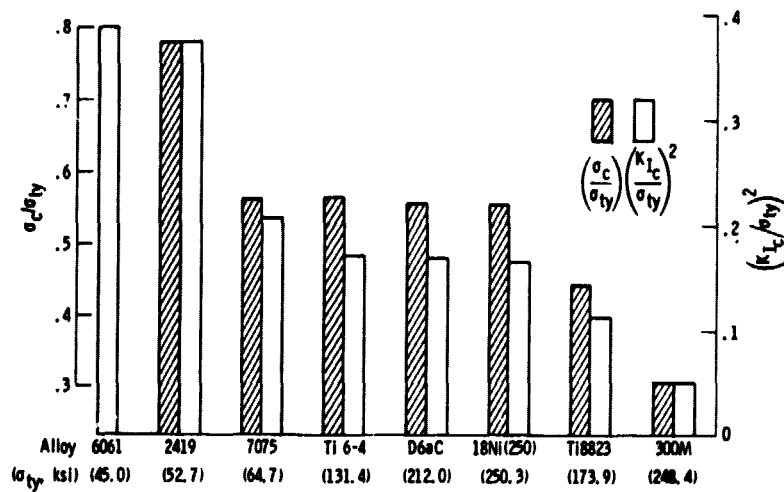
Figure 15. - Alloy ratings by DENC screening specimen and by K_{I_c} data for W/B = 2, W = 2, B = 1.